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RONMENTAL PROTECTION DIVISION

Report No. 225

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PHYSIOLOGY OF LOAD-CARRYING VII

Quartermaster Research & Development Command

Quartermaster
Research & Development Center

March 1954 Natick, Massachusetts

THIS REPORT CONCERNS

assessment of some of the characteristics of the experimental load-carrying system T 53-8. It also reviews some of the principles which may be useful in future load-carrying studies.

IT IS FOR THE USE OF

designers of load-carrying systems, field and laboratory evaluation agencies, and wearers of military web equipment.

THE APPLICATION FOR THE ARMY IS

to guide design and procurement of web equipment systems having favorable features for load-carrying under stressful and active conditions. The report can also be helpful to those in the Department of Defense concerned with the problems of determining requirements of personal equipment for military use.

HEADQUARTERS QUARTERMASTER RESEARCH & DEVELOPMENT COMMAND
QUARTERMASTER RESEARCH & DEVELOPMENT CENTER, US ARMY
NATICK, MASSACHUSETTS

Environmental Protection Division
Report No. 225

A STUDY OF THE EXPERIMENTAL PACK T 53-8

WITH A REVIEW OF METHODS FOR STUDYING LOAD-CARRYING SYSTEMS

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FOREWORD

Interpretations of the effects of load-carrying systems upon men have been, in the past, largely confined to the relatively static condition of marching. In considering the load for use in combat, dynamic interpretations and actual measurements of performance under high velocity have not been possible, because of inadequate methods of measurement. In the present report, the T 53-8 load-carrying system has been compared to other systems by methods which evaluate the effect of the pack on the man at all times during a complex activity. The methods described here, combined with the suggestions for the design of experiments, are extremely promising for obtaining objective measurements of the many rapidly occurring interactions between the man and his personal equipment in load-carrying and other military situations.

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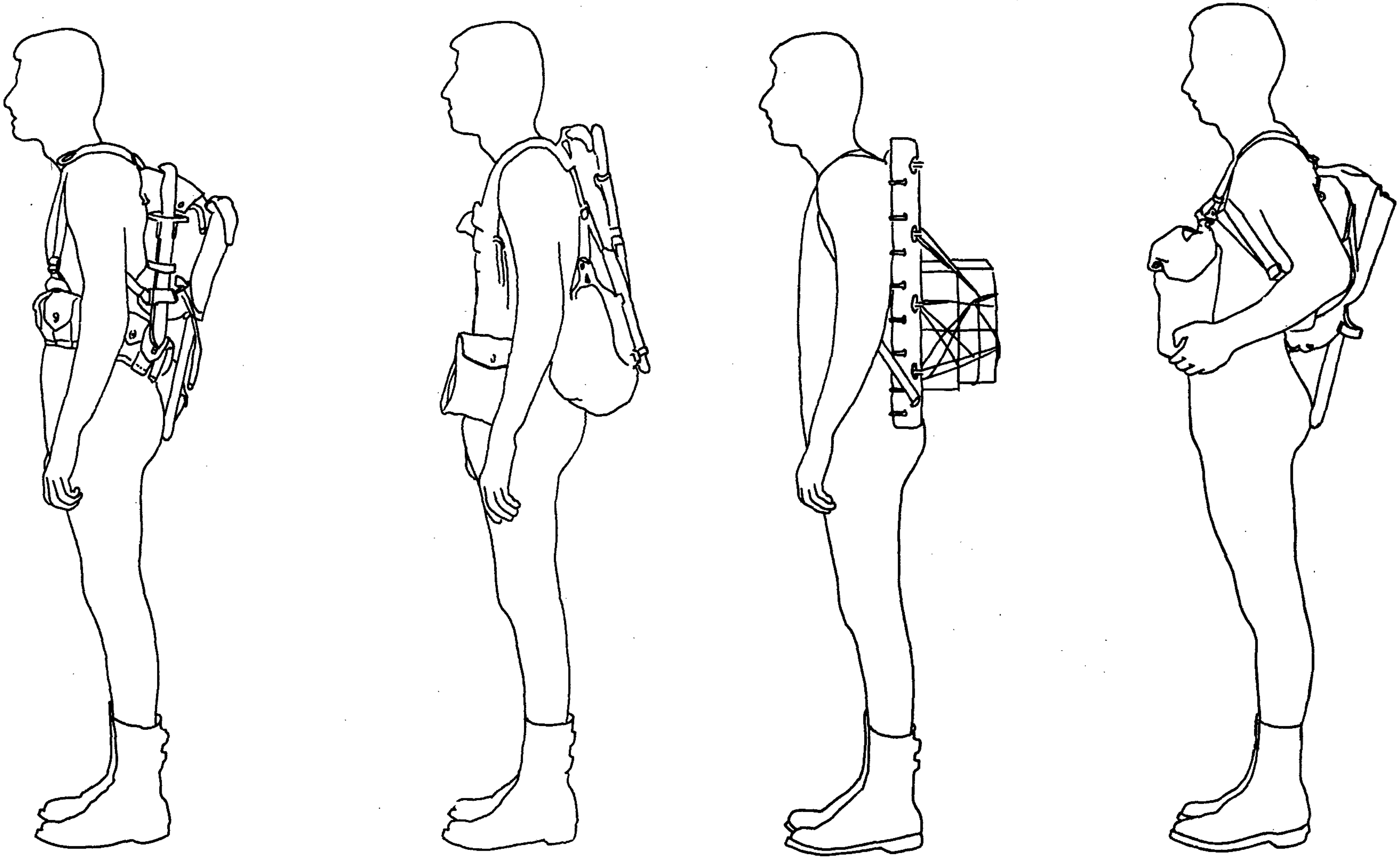


STANDARD COMBAT PACK   T 53-8 COMBAT PACK   PACKBOARD   UNITED KINGDOM Z-2

PROFILES OF LOAD-CARRYING SYSTEMS STUDIED

A STUDY OF THE EXPERIMENTAL PACK T 53-8 WITH A REVIEW OF METHODS FOR STUDYING LOAD-CARRYING SYSTEMS

1. Introduction

a. Test Rationale

Since this is the first study using physiological measures in a test of load-carrying systems by this Division, it is as much a study in methodology as it is a study of a specific end item.

At the outset of attempts to develop useful laboratory and field criteria of the effects of different packs on men a general statement of test rationale may be of interest. No claim, however, is intended that this study actually achieved the ideals set forth here.

The study should be designed and carried out in such a manner that the results not only answer specific questions, but also contribute to the pool of general information on the item of personal equipment and its effect on the soldier. Since the expense of studies using human subjects is substantial, a well designed experiment that produces the maxima of usable data is economically sound because it decreases development time and increases the fruitful utilization of scientific personnel. The concept of obtaining the maximum of generally useful information depends upon an appropriate mixture of laboratory and field study rather than any alleged superiority of field over laboratory results or vice versa.

To help assure validity of test methods and to give them "meaning" in the sense of serving as the basis for predicting what may occur under a number of conditions, there should be continual communication between application of techniques and the areas of background research related to the test methods and previous experience. This means that bridges between the accuracy of laboratory measurement and the realism of field study are not only desirable, but necessary, for full utilization of resources. A testing method may appear to be valid on the grounds that it simulates the real conditions of use. This is no guarantee that the important factors have been measured. "Face validity" of a test may be dangerously close to superficial plausibility.

Standards should be included in all studies as concurrent controls. Standards not only serve as a control on the variability of test subjects from experiment to experiment, but are also the basis for permitting comparisons of items studied at different times. Standards must be specific to the variables being observed. For example, for metabolic rate studies we have used loads mounted on the lower half of a packboard as a reference standard for the comparison of other load distributions. This standard, however, would not be suitable for the determination of webbing distribution or length.

Failure to use the newer statistical techniques for evaluating the effects of multiple variables leads to wasteful use of the information collected. The use of statistically designed experiments permits the separate and combined assessment of various design features in a series of packs. In such a design, quantitative features of interest may be varied in amount and their importance to a whole ensemble evaluated.*

Usually the best way to obtain evaluation of design features is to treat them as experimental variables which can be systematically varied in amount as well as kind. This often means "idealizing" particular features for experimental purposes in order to determine optimal design values. Once matters of opinion become matters of fact in the idealized form, compromises are usually necessary in order to incorporate the optimal values into practical equipment. Under these conditions, the role of the expert becomes that of interpreter rather than that of an informed guesser. With regard to load-carrying equipment, "idealization" implies that experimental equipment should be designed with a potential for varying the location, size, length or other properties or other features under consideration. The combination of known desirable features from several sources leads to a greater probability that a decision regarding the superiority of one item over another can be meaningfully made.

b. Features of the T 53-8 Pack

The T 53-8 is a design similar in concept to Canadian and UK experimental designs and is a design which attempts to meet the following considerations:

(1) Fore and aft balance of the load by carrying of some of the load anteriorly in general purpose pouches. This permits the subject to walk with less forward lean. Evidence has been accumulating that methods of carrying which produce forward lean are associated with a more rapid increase of energy expenditure with given increases of load weight. Hale & Karpovich[6] state that the imposition of forward lean is considered uncomfortable by men, and believe this is the reason men tend to prefer a high rather than a low back load. Erect posture is achieved by having the center of gravity of the load near, above, below, or at the center of gravity of the body.[2] In the instance of the T 53-8, the low back pack is balanced by ammunition pouches in front. The center of gravity of the load is presumably above and near the center of gravity of the body which is located in the pelvis.[2] Some users of the system suggest wear of the pouches at the side instead of in front. This will shift the center of gravity posteriorly.

(2) Minimizing motion of the load during locomotion. Studies in this Division have shown that 15 pounds carried in mid-thigh cargo pockets require an energy expenditure at 3.5 mph on a treadmill as large as 45 pounds on the back.[13] By keeping load mass off the extrem-

*An excellent discussion on the use of statistical design in experiments as given by Wilson.[14]

ities and by locating most of the load near the center of gravity of the body, participation of the load mass in the "extra" motions required for maintaining equilibrium and producing locomotion is minimized.

(3) Stabilizing of the load by maintaining it in such positions that it undergoes a minimal change of position relative to the carrier during locomotion. "Bouncing" and "banging" of load components against the body not only produce local discomfort, but also require additional energy.

c. Description of Load-Carrying Systems Used in Studies

The T 53-8 pack was compared to a Standard Combat Pack, the experimental United Kingdom (Z-2), and a packboard.

(1) Table I lists the weights of the load components.

TABLE I: WEIGHTS OF COMPONENTS IN PACK SYSTEMS STUDIED*

	Pounds
T 53-8	
Pack	5
Entrenching tool combination	4-1/2
Ammunition pouches (w/ammunition and two hand grenades)	12
Canteen (w/water)	3-1/2
	25
Standard Combat Pack	
Pack (w/two hand grenades)	11
Entrenching tool combination	4-1/2
Ammunition belt w/ammunition	6
Canteen (w/water)	3-1/2
	25
United Kingdom (Z-2)	
Pack	5-1/2
Entrenching tool combination	4-1/2
Ammunition pouches (w/ammunition and two hand grenades)	12
Canteen	3
	25
Packboard	
Packboard frame	6-1/4
6 "Standard" blocks	18-1/4
	24-1/2

*Ammunition consisted of M-1 rifle ball ammunition with charge removed. It was not possible to obtain M-1 rifles, hence, no attempt was made to include this feature of combat realism.

(2) The Standard Combat Pack was worn on the upper portion of the back with entrenching tool and bayonet mounted on the rear of the pack. The major portion of the load was therefore carried on the upper portion of the back below the top of the shoulder.

(3) The experimental United Kingdom pack (Z-2) differed from the T 53-8 pack in that the ammunition pouches were longer and that the pack in the battle order studied was worn higher than the T 53-8.

(4) The packboard used was a standard plywood packboard held in place only with shoulder straps. Loads consisted of weighted wooden blocks 3 x 5 x 13 inches, which were tied to the lower half of the packboard.

d. Organization of the Studies

Because several approaches to the problem of evaluating packs have been tried, this report is organized in the following manner:

Energy expenditure studies
Performance tests
Dynamic physical measurements

Under each of these sections, separate methods, results, and discussion are found.

2. Energy Expenditure Studies

a. Methods

The oxygen consumption was measured on four subjects while carrying the different types of load on a treadmill with belt speeds of 2.5, 3.5, and 5.0 mph. A closed system Tissot spirometer supplying pure oxygen was used to measure the metabolic rate for the 16th through 18th minutes of each walking period.

Because of the unavailability of treadmills at Lawrence and Natick, the treadmill studies were conducted at Springfield, Massachusetts, through the courtesy of the Department of Physiology, Springfield College. The subjects wore GI herringbone twill cotton fatigue uniforms and jungle boots. Three of the four subjects being studied recently returned from the Yuma Test Station, where they had been carrying 25- to 40-pound loads over hot sand in 100+° heat, and they appeared to be in excellent physical condition. The other subject, Pe, was apparently in very poor physical condition and gave erratic results.

The characteristics of the subjects are given in Table II.

TABLE II: CHARACTERISTICS OF SUBJECTS

Subject	Age	Weight	Height	Surface Area	Body Fat*
	years	pounds	inches	sq. meter	percent
We	21	159	70.9	1.91	2.1
Pa	21	156	69.4	1.86	3.5
Ra	22	161	70.8	1.92	4.5
Pe	23	153	67.6	1.81	7.0

*Determined by the skin-fold method of Brozek & Keys, as modified by Newman.[11]

b. Results

The metabolic rates determined with subjects walking at 2.5 mph with 25- and 40-pound loads are indicated in Table III.

TABLE III: ENERGY EXPENDITURE ON TREADMILL AT 2.5 MPH (Cal./M^2/hr.)

Subject	No Load	25-Pound Load			40-Pound Load	
		T 53-8	Standard	Packboard	T 53-8	Packboard
We	125*	137	128	--	132	142
Pa	139*	149	164	140	152	163
Ra	131*	155	134	--	158	158
Pe	144*	168	162	141	168	154
Mean	134.8	152.2	147.0	140.5	152.5	154.2
Mean w/o Pe	131.7	147.0	142.0	--	147.3	154.3

*Mean of two determinations

At 2.5 mph only the "standard" high pack combat load and the experimental T 53-8 low back combat pack were compared on all subjects. At this speed the T 53-8 system averaged 5.2 Cal./M^2/hr. higher than the standard pack. This difference is not statistically significant ($t = .987$). At the slow speed of 2.5 mph on the treadmill each subject's gait was noticeably unstable.

The metabolic rate involved in load-carrying at 3.5 mph treadmill belt speed for the unloaded condition and the four pack types are given in Table IV.

TABLE IV: ENERGY COST OF MEN CARRYING 25-POUND LOADS AT 3.5 MPH TREADMILL SPEED
(Cal./M^2/hr.)

Subject	No Load	T 53-8	Standard	Packboard	UK
We	172	186*	177*	193	186
Pa	154	197*	192*	197	199
Ra	152	204*	196*	198	197
Pe	237	216*	217*	197	245
Mean	178.8	200.8	195.5	196.2	206.8
Mean w/o Pe	159.3	195.7	188.3	196.0	194.0

*Mean of two determinations

The difference between the standard and the T 53-8 systems is not statistically significant when all four subjects are compared ($t = 2.25$ $P < .2$). When the statistical comparison is made between the standard and T 53-8 systems omitting subject Pe, the standard has a statistically significantly lower energy cost than the T 53-8 ($t = 5.671$ $P < .05$). The experimental UK design (mean 194.0 Cal./M /hr.) also involves a significantly greater energy expenditure than the standard at this velocity ($t = 4.559$ $P < .05$). While these differences are significant on statistical test, they are actually quite small in magnitude in the instance of the standard and the T 53-8, the difference being 3.7 percent. The calculations on the standard and T 53-8 are based on the mean of two replications each. The replications were not significantly different from each other.

Since some of the basic concepts of the T 53-8 and the United Kingdom (Z-2) are similar the reason for the apparent difference is not clear. It is possible that the larger and longer general purpose pouches may interfere with freedom of thigh motion.

The pulse data available for the men during walking are given in Table V.

TABLE V: PULSE RATES AT 3.5 MPH ON TREADMILL
(Beats per Minute)

Subject	No Load		T 53-8		Standard	
		Mean		Mean		Mean
We	96, 100, 106, 96	99.5	100	100.0	99, 104	101.5
Pa	76, 84, 80	80.0	90, 84	87.0	82	82.0
Ra	88, 99, 90	92.3	98	98.0	108	108.0
Mean		90.6		95.0		97.2

A comparison of metabolic rates was also carried out at five mph in an attempt to bring out differences between packs by accentuating the acceleration and deceleration factors involved. The metabolic rate data for the comparison of four load-carrying systems at five mph of treadmill belt speed are given in Table VI.

TABLE VI: ENERGY COST OF FOUR MEN CARRYING 25-POUND LOADS AND WALKING AT 5.0 MPH ON TREADMILL
(Cal./M^2/hr.)

Subject	No Load	T 53-8	Standard	Packboard	UK
We	384	381	407	450	417
Pa	352	361	384	466	438
Ra	331	393	386	369	436
Pe	483	470	518	496	591
Mean	387.5	401.2	423.8	445.2	470.5
Mean w/o Pe	355.7	378.3	392.3	428.3	430.3

At this speed the relationship between the standard and the T 53-8 is reversed with the T 53-8 next above the no load values, then the standard, and then the packboard. The readings are, however, variable and the differences between these systems are not statistically significant. The experimental UK model showed a significantly greater energy expenditure than the T 53-8 ($t = 3.665$ $P < .05$), but was not significantly higher than the other two systems.

The three different speeds on the treadmill made it possible to test the hypothesis that differences in balance, "hobbling," and energy requirements for accelerating the loads would be accentuated by greater speed. The differences between 3.5 and 5.0 mph, calculated from Tables V and VI, are given in Table VII.

TABLE VII: DIFFERENCE BETWEEN 3.5 AND 5.0 MPH ON TREADMILL ($Cal./M^2/hr.$)

Subject	Difference T 53-8	Difference Standard
We	195	230
Pa	164	192
Ra	189	190
Pe	264	301
Mean	203	228

At 5.0 mph all subjects showed an energy cost increase over the 3.5 mph rate. There was a greater increase in every instance with the standard than with the T 53-8. This greater difference was statistically significant ($t = 3.76$ $P < .05$). In the 2.5 and 3.5 mph studies, the T 53-8 averaged 48.2 $Cal./M^2$/hour higher at 3.5 than at 2.5 mph, and the standard averaged 48.5 $Cal./M^2$/hour higher, an insignificant difference.

c. Discussion of Metabolic Rate Studies

Results of the energy expenditure observations are that at slow speeds there is little difference in the load-carrying systems, though there may be some advantage for the high back location of the standard combat load; but at a higher speed, five mph, the advantage appears to shift to the T 53-8. At slow speeds dynamic aspects are relatively unimportant; at greater speeds the dynamic factors such as acceleration and impact appear to dominate the physical energy component of pack movements.

Objective evidence and theoretical considerations support the concept that it may be better to carry loads low on the body. Field experience supports the idea that high back loads are more easily carried. The nature of this conflict in viewpoint is dramatically illustrated by information which one of the authors obtained in informal discussion with Cpl Kenneth Jones, US 52095366, concerning his combat experience in Korea. He stated that his officers instructed the men to wear the combat pack as high as possible, but when the men were forced to run they "took the packs off and carried them by hand!"

3. Performance Tests

In the process of developing tests for the evaluation of packs some studies of a performance type were tried. These consisted of running over an obstacle course of automobile tires, "hitting the dirt," and running upstairs in the Lawrence (Massachusetts) Memorial Stadium.

a. Tire Obstacle Course

The obstacle course consisted of a series of 16x6.00 automobile tires set in a line, with the tires offset by being tangent to the center line, alternating right and left, with 51 inches between centers. The initial arrangement used is indicated as straight course in Figure 1.

TIRE OBSTACLE COURSE

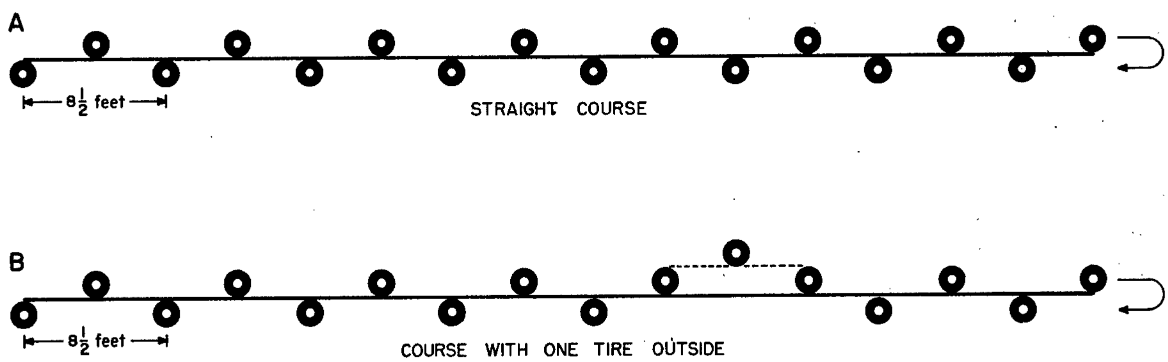


FIGURE 1

Running through this course brought out effects from lateral, vertical, and anteroposterior acceleration and deceleration by the nature of the stepping required for negotiating the course. Practice effects were apparent. It was decided that careful training was required to decrease the danger of sprained ankles during an actual test. The subjects wore GI fatigue uniforms and jungle boots.

For the straight course (Figure 1) the average time for eight men to complete the course and return unloaded was 11.1 seconds. With 25 pounds carried as the T 53-8 experimental pack the time was 11.4 seconds.

To emphasize the differences the course was modified by placing one tire on the outside as shown in Figure 1. The modification added a difficult problem in body rotation about a vertical axis to the acceleration and jumping in three directions. The results of this test are given in Table VIII.

TABLE VIII: TIME TRIALS "TIRE OUTSIDE"
(seconds)

Subject	No Load		Standard	T 53-8	High Packboard	Low Packboard
		Mean				
Ha	12.4, 11.8	12.1	13.4	13.2	14.7	13.9
We	13.2, 11.4	12.3	12.5	12.5	15.0	13.7
Pa	11.7, 10.9	11.3	12.6	11.8	14.1	13.4
Pe	12.9, 12.9	12.9	13.0	13.0	14.6	14.9
Mo	17.0, 13.9	15.4	15.4	16.4	17.4	16.0
Va	12.3, 11.6	12.0	12.6	13.2	14.9	13.4
Mean		12.67	13.25	13.35	15.12	14.22

An analysis of variance showed significance at the one percent level. The time difference was statistically significant between both the T 53-8 and the standard pack systems and the two packboard conditions ($P < .05$). The difference was not significant, however, between the T 53-8 and the standard pack. It is of interest that the difference between the high and low packboards was statistically significant and that under these conditions the high packboard was a particular disadvantage.

Four subjects completed more extensive tests on this course in a comparison of No Load, T 53-8, and the Standard Combat Pack. These results are shown in Table IX. In this table runs with more than two errors* are omitted.

TABLE IX: FURTHER TIME TRIALS "TIRE OUTSIDE"
(seconds)

Subject	No Load	Standard	T 53-8
Ha	11.37 (6**)	12.67 (3)	12.40 (2)
We	11.62 (5)	12.13 (3)	11.75 (2)
Pa	10.82 (2)	11.90 (3)	11.70 (3)
Va	11.62 (5)	12.50 (3)	12.93 (3)
Mean	11.358	12.300	12.195

**Number in parenthesis = number of replications

*If the hole in center of the tire was missed it was counted as an error.

An analysis of variance of the time trials on the tire course for the data shown in Table IX did ~~not~~ demonstrate significant differences in the time required to run the course while wearing the different packs ($P < .01$). The difference between the running time with the T 53-8 and the unloaded condition was significant ($P < .05$). The increase in time for the standard load over the unloaded condition was highly significant ($P < .01$). The mean difference between the "standard" high and the T 53-8 low combat loads was not significant.

Questioning of the subjects following the tire run test indicated the following:

(1) Carrying the packboard with either high or low weight distribution was extremely difficult; it was considered an impractical method of load-carrying under these conditions.

(2) The pack of the T 53-8 experimental design was much more stable during the run than the standard high position combat load.

(3) The pouches of the T 53-8 system frequently caused pain by pounding on the lower abdomen and upper thigh. Bruises and skin abrasions were produced in some subjects. Some suggested that the pouches were placed in too low a position.*

(4) The best place to carry the entrenching tool for the T 53-8 ensemble was on the cross strap.

b. <u>Slow Motion Photography on Tire Obstacle Course</u>

The time trials over the tire obstacle course did not indicate that the method has promise for routine use as a sensitive power test in demonstrating small differences between pack systems. Slow motion pictures of men running over the tires strikingly indicated, however, some of the problems of acceleration and deceleration of load components in different directions.

Features which are apparent in this movie photographed at 64 frames a second and projected at 16 frames per second include the following:

(1) The packboard with the low distribution of weighted wood blocks was observed to have extensive sidesway. Oscillations of the pack were frequently out of phase with motions of the man during the sidewise hopping from tire to tire.

(2) All packs showed some degree of vertical "shucking" up and down of the entire load-carrying systems. With the T 53-8 system this was largely vertical, whereas the standard combat load rotated around a transverse axis as well as rising and falling vertically.

*Recent recommendations, however, have been for more lateral wear of these pouches than employed in this study.

(3) The Standard Combat Pack with a center of gravity located several inches out from the upper back showed serious oscillation in many directions, frequently out of phase with the motion of the body. In other words, the pack "zigs" while the man "zags," and in the slow motion pictures the effect of this on the man's pace can be readily seen. As the load is suddenly stopped or started, or bangs into the man, corrective motions to maintain posture or stride are evident.

(4) Location of the entrenching tool on the pack leads to much less swinging and banging of this item than when it is fastened to the belt.

(5) "Flopping" of the water-filled canteen is a problem with all systems.

(6) The major problems evident with the T 53-8 are the vertical rise of the entire system and particularly the swinging of the ammunition pouches.

(7) At the present time the observation of slow motion movies obtained on this course gives more useful information on dynamic pack performance than the individual quantitative measurements described elsewhere in this report.

c. Running and Falling Studies

Three of the subjects used in the tire course experiment ran 400 yards, as fast as they could, with the T 53-8 pack. All subjects complained that various components, particularly the pouches and canteen, beat against the body. It is of interest from the standpoint of dynamic factors that when these three subjects ran up and down the steps of the Lawrence Memorial Stadium, the T 53-8 felt quite stable and comfortable in contrast to running on level ground.

Three subjects were employed in a test covering a 32-yard course running at their top speed, falling to the ground and rising every eight yards. Markers were placed at eight-yard intervals to indicate where falls should be performed. The test was very rugged and only two conditioning runs were made before actual measurement. Rifles were not carried. The means of the time in seconds required to run the course, based on two trials for each pack, are listed for each man in Table X. All men had faster runs with the T 53-8 than the Standard Combat Pack. The mean difference of 1.5 seconds approaches statistical significance ($t = 3.947$, a t value of 4.303 is required for the .05 significance level), and since the direction of the difference was consistent for each subject, it appears reasonable to predict that a larger number of subjects would establish statistical verification. With the T 53-8, subject Pa considered the pouches moderately painful in falling, while the other two subjects considered it extremely painful. With the standard pack, subject Pa observed that the pack hit the back of his head on landing; subject We observed that the pack shoved up during the fall, while subject Ra noted that the standard pack actually "tends to throw one over." All subjects had the impression that they slid farther on the ground with the standard than with the T 53-8.

TABLE X: TIME REQUIRED FOR THREE SUBJECTS TO COVER 32 YARDS "HITTING THE DIRT" AT EIGHT-YARD INTERVALS
(seconds)

Subject	Standard	T 53-8
Pa	9.8	8.2
Ha	11.6	10.8
We	11.1	9.0
Mean	10.83	9.33

In general, the conclusion from this performance test is that the location of the center gravity of the T 53-8 appears to confer an advantage in falling despite the pain occasioned by landing on the pouches.

d. Performance Tests Reported by Canadian Investigators

The Canadian investigators have studied a number of performance tests for evaluating load-carrying systems.[1,7] For example, Hunter & Turl[7] have used performance tests for study of the Canadian Battle Order and Fighting Order. The Battle Order studied was similar in general load distribution to the Standard Load in the present study except that the Canadian system had ammunition pouches anteriorly as in the T 53-8. The small pack in the Canadian study weighed eleven pounds and the basic pouches 12-1/2 pounds. The Canadian Fighting Order had 12-1/2 pounds mounted anteriorly as basic pouches. There is no back pack, but a five-pound gas cape-roll was carried at the waist posteriorly. A 4-1/2 pound shovel was carried in the mid-line of the back in both instances. A three-pound bandolier was worn in both cases. A 2-1/2 pound helmet was worn and a nine-pound rifle carried.

(1) In a 25-yard sprint the average time was 4.69 seconds for the Battle Order. The Fighting Order was significantly faster, the time being 4.53 seconds ($t = 2.444$ $P < .05$).

(2) In a 50-yard sprint the average time was 8.52 seconds with the Battle Order and 8.17 seconds with the Fighting Order. This difference was highly significant ($t = 4.869$ $P < .01$). With a 100-yard dash the average time of the same 31 men with the Battle Order was 16.77 seconds, and Fighting Order 16.39 seconds, which was also significantly faster ($t = 2.473$ $P < .05$).

It was particularly noteworthy that the men in the Battle Order believed that they could not run farther than the 100 yards, while in the Fighting Order they had not yet reached their considered limit of physical output. It is suggested that ability to run more than 100 yards at top speed might be important in combat.

e. Discussion of Performance Studies

Performance tests appear to vary widely in their sensitivity for use in evaluating load-carrying systems. Complex obstacle courses have rarely been found to be sensitive measures. Their very complexity confounds the effects from the experimental variables of interest, with those of the test situation. The time for a running dash shows considerable promise for meeting the requirements of a test which is easy to administer and has sufficient sensitivity for discriminating differences in load-carrying systems. The technique for conducting such a test has not been standardized, however, or have variations in technique been sufficiently investigated to conclude that a measure which is optimally sensitive has been found. The Canadian studies suggest that a 50-yard dash is more sensitive than a longer or shorter distance.[7] Further studies to determine optimal distances and instructions to the subjects are indicated by the Canadian results. In addition, investigations of such other tests as the time required to run a measured distance and halt on a signal by the test administrator, and the time required to run a zigzag pattern in which the turning points are irregularly and unpredictably (to the subject) called off by the test administrator, may be worthwhile.

4. Dynamic Physical Measurements

In the series of reports on load-carrying which have been published to date,[3,13] evidence has been presented which is best explained in terms of acceleration and deceleration which loads must undergo when suspended in different ways. These studies have pointed out the importance of dynamic aspects of the combat load-carrying problem rather than the more static aspects which are particularly relevant to the carrying of heavy loads.

Several lines of investigation on methods for studying the dynamic aspects of load-carrying are underway. These methods include stroboscopic photography, the strain gauge accelerometer, a pneumatic strap pressure measure, and a pressure sensitive device ("filpip") developed under a Quartermaster Corps contract between the Pioneering Research Laboratory and the Franklin Institute, both of Philadelphia.[5] The present report is limited to some preliminary results from the stroboscopic photography method and a discussion of some data from the pneumatic pressure method.

a. Stroboscopic Analyses

The stroboscopic method currently used is a modification of a technique developed by New York University for evaluating artificial legs.[4]

The modification involves the use of a "strobotac" (a timing device) and a "strobolume" (which controls flash interval) that produces brilliant flashes of light. The flash rate selected for this study was 20 per second. The strobolume is an argon discharge tube which produces much of its light in the blue region of the spectrum. Patches of blue "scotchlite" were mounted on various portions of the man and pack system. This glass-beaded material is familiar as a light reflecting material on automobile bumpers. The scotchlite has the property of reflecting light back to its source. The arrangement is such that brilliant blue flashes of light are reflected back to the camera mounted beside the strobolume, and provide a record of the location of the man and load-carrying system at the selected flash intervals. With this method general illumination is possible and the subject need not walk in the dark.

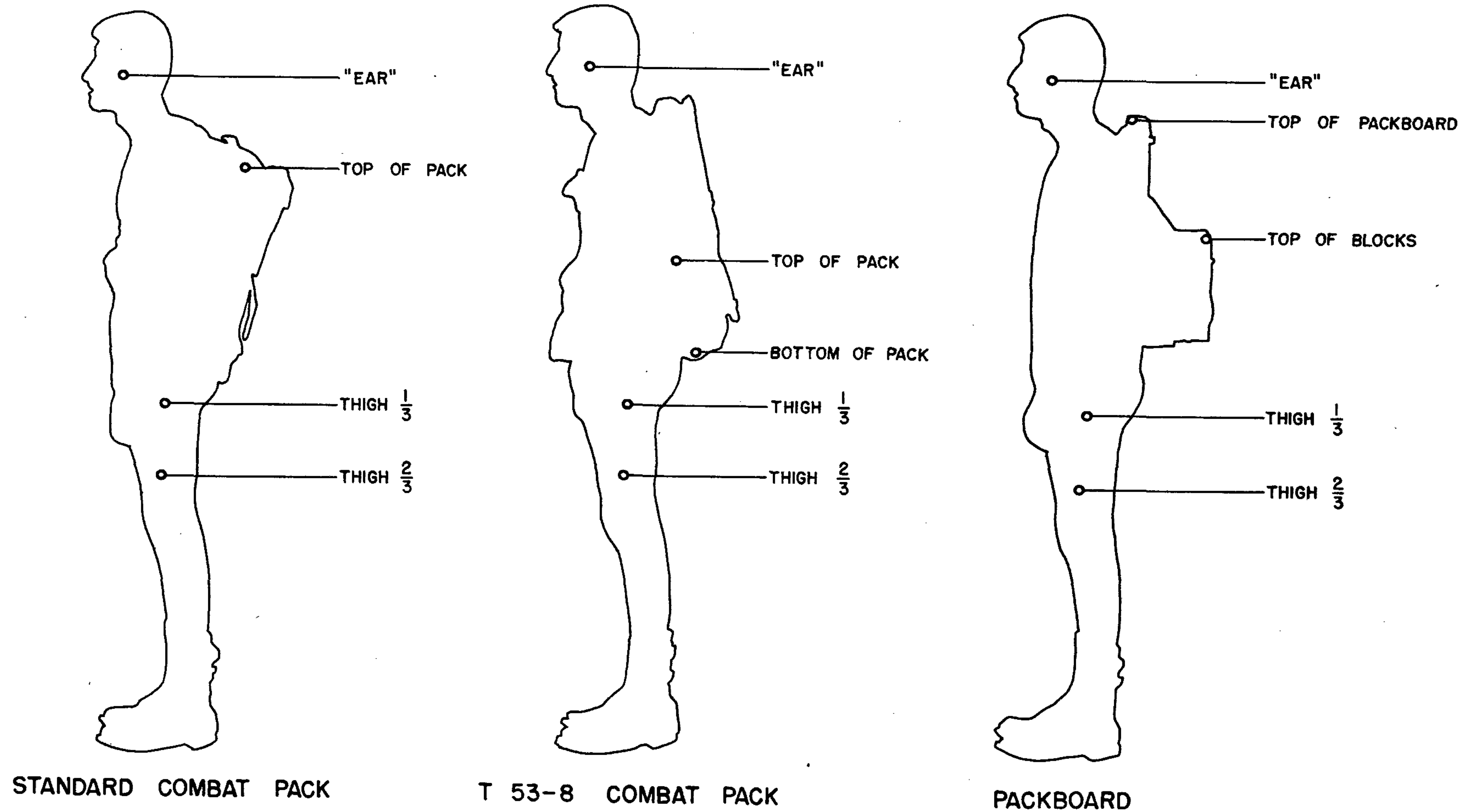
The single subject used, Ha, weighed 140 pounds and was dressed in GI long underwear which had been dyed black. The distribution of scotchlite markers used on subject Ha with the Standard Combat Load, the T 53-8 combination and the packboard are shown in Figure 2. He walked at 3.7 mph and ran at 6.2 mph on a wood floor for the series of photographs.

In Figures 3, 4, and 5, horizontal velocity curves are shown for the subject while running with packboard, standard and T 53-8 packs. In these figures the overall velocity is indicated and the velocity of other points in relation to this appear as swings above or below the line.

The point at the temporo-mandibular joint, referred to as "ear" in the figures, is used as a reference point on a relatively fixed portion of the body. This location is visible throughout the walking cycle. Most of the other scotchlite markers were placed on clothing and packs where some slipping and flapping occurred. From the standpoint of interpretation of body mechanics, a fixed point on the side of the hip at the center of gravity of the body would be desirable. The use of the hip is complicated by the swing of the arm which obscures this area as it swings past during locomotion.

Two points are shown on the thigh, one approximately one-third, the other two-thirds of the distance from the hip joint to the knee. These two points indicate approximately the points at which a cargo pocket is ordinarily located on uniforms.

Points on the different loads are not comparable and when the technique, here presented in preliminary form, is fully developed, the centers of gravity and moments of rotation of the load may be determined.



LOCATION OF "SCOTCHLITE" MARKERS FOR STROBOSCOPIC PHOTOGRAPHY

FIGURE 2

HORIZONTAL VELOCITY OF LOAD SYSTEM COMPONENTS DURING RUNNING

STANDARD COMBAT PACK

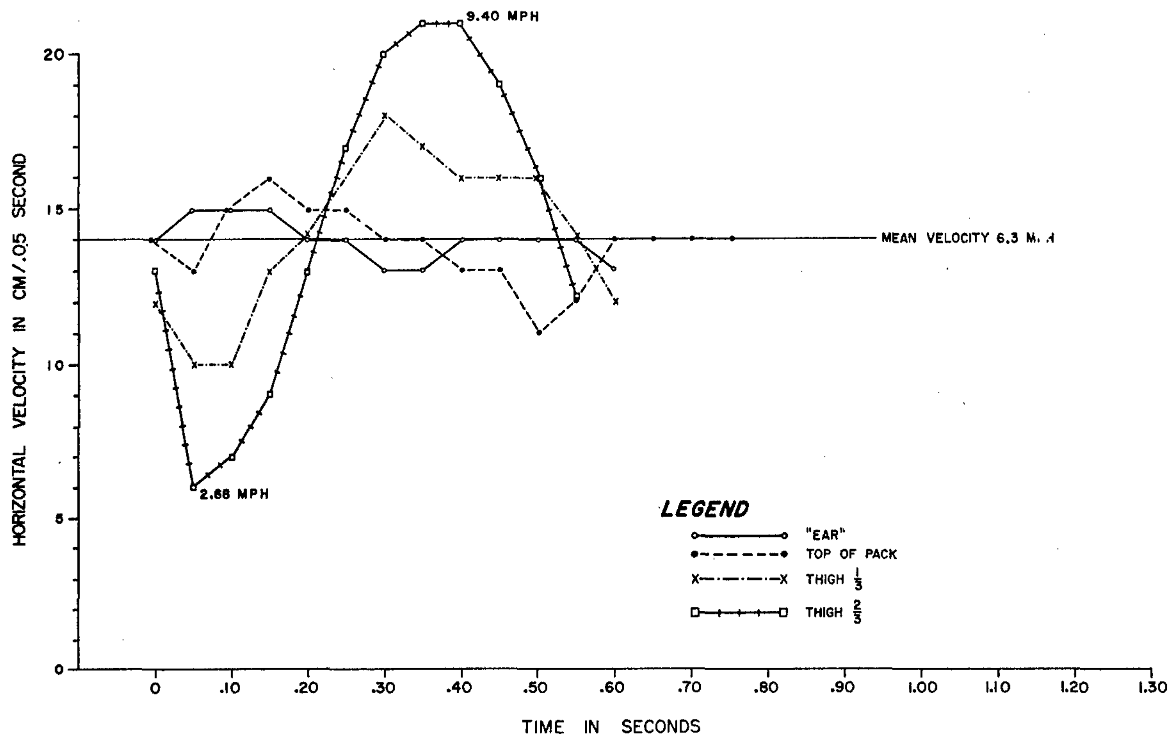


FIGURE 3

HORIZONTAL VELOCITY OF LOAD SYSTEM COMPONENTS DURING RUNNING

T 53-8 COMBAT PACK

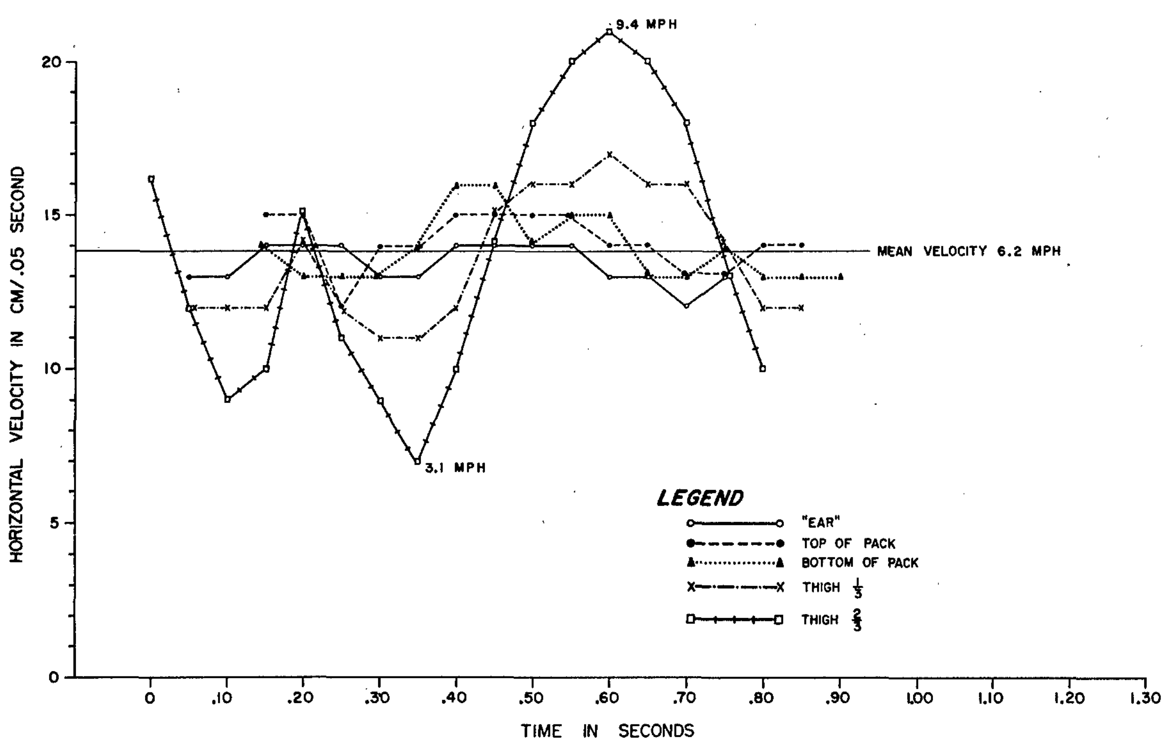


FIGURE 4

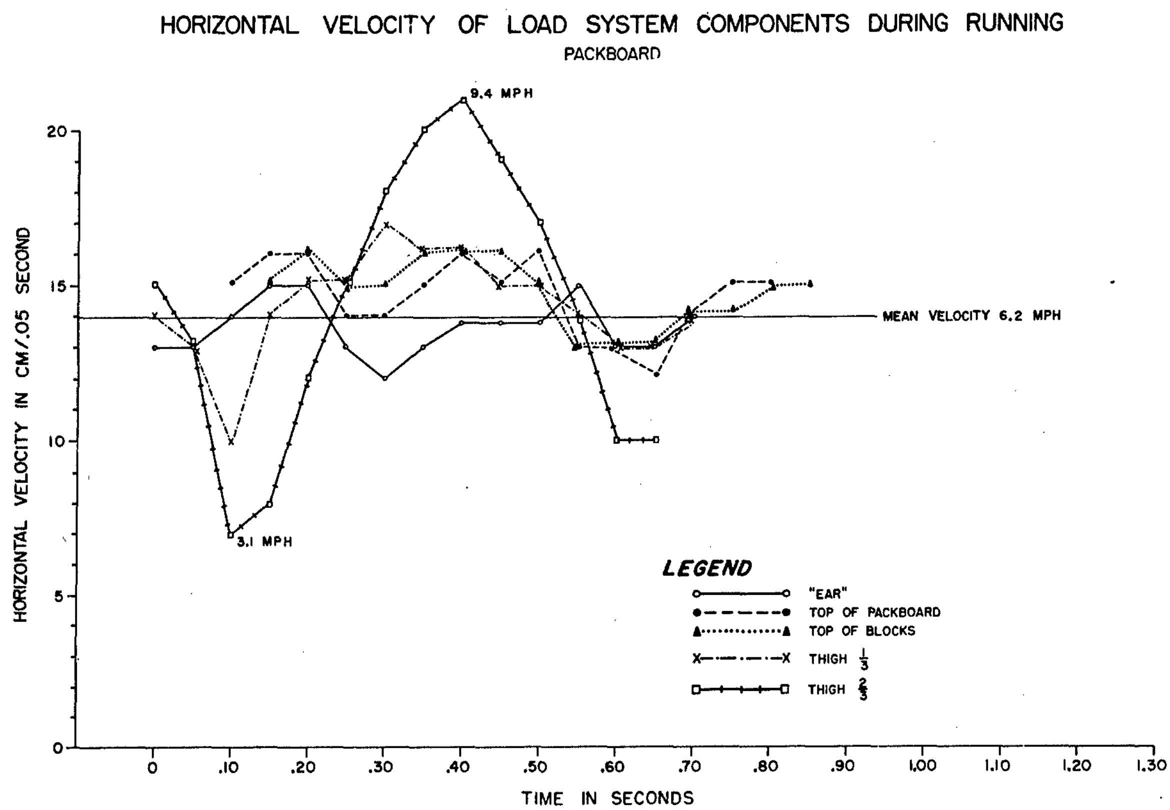


FIGURE 5

In Table XI the maximal and minimal horizontal velocities observed in one pace are shown for various components of each pack system in both the running and walking conditions. The variation in velocity of the thigh points is in accord with the high energy expenditure associated with thigh pocket loads observed in another report.[13]

While walking at 3.8 mph the maximal forward velocity of the Standard Combat Pack was 4.5 mph and the minimal speed 3.6 mph. With the T 53-8 pack on a man walking at 3.7 mph the pack varied in horizontal forward velocity between 3.1 and 4.5 mph suggesting little difference between packs at the walking speed. During running with the standard pack at a forward velocity of 6.1 mph the pack varied in forward velocity from 4.9 to 7.2 mph. With a man running at 6.1 mph the T 53-8 pack speed varied between 5.4 and 6.7 mph. The data, while requiring confirmation by additional studies, suggest that the T 53-8 is more stable in the anteroposterior line than the Standard Combat Pack.

TABLE XI: MAXIMAL AND MINIMAL HORIZONTAL VELOCITIES IN ONE PACE (values without parenthesis in miles/hr; values within parenthesis in cm/.05 sec.)

		Standard		T 53-8		Packboard	
		Walk	Run	Walk	Run	Walk	Run
Paces/mile		914	879	914	838	909	821
Overall velocity		3.75 (8.38)	6.13 (13.71)	3.74 (8.35)	6.13 (13.71)	3.77 (8.43)	6.26 (14.00)
"Ear"	Max	4.03 (9)	6.71 (15)	4.03 (9)	6.26 (14)	4.03 (9)	6.71 (15)
	Min	3.58 (8)	5.82 (13)	3.13 (7)	5.37 (12)	3.58 (8)	5.37 (12)
Pack	Max	4.47 (10)	7.16 (16)	4.47 (10)	6.71 (15)	4.47 (10)	7.16 (16)
	Min	3.58 (8)	4.92 (11)	3.13 (7)	5.37 (12)	3.58 (8)	5.37 (12)
Pouch	Max	—	—	4.92 (11)	7.16 (16)	—	—
	Min	—	—	3.13 (7)	5.37 (12)	—	—
Shovel handle	Max	4.47 (10)	8.50 (19)	4.92 (11)	6.71 (15)	—	—
	Min	3.13 (7)	4.92 (11)	3.13 (7)	5.37 (12)	—	—
Thigh 1/3	Max	5.37 (12)	8.05 (18)	5.37 (12)	7.61 (17)	5.37 (12)	7.61 (17)
	Min	2.68 (6)	4.47 (10)	2.68 (6)	4.92 (11)	3.13 (7)	4.47 (10)
Thigh 2/3	Max	6.71 (15)	9.40 (21)	6.71 (15)	9.40 (21)	6.71 (15)	9.40 (21)
	Min	1.34 (3)	2.68 (6)	1.79 (4)	3.13 (7)	1.34 (3)	3.13 (7)

In Table XII maximal vertical velocities are shown for the up and down phases of the various pack components.

TABLE XII: MAXIMAL UP AND DOWN VELOCITY OF VERTICAL COMPONENT IN ONE PACE
(values without parenthesis in miles/hr; values within parenthesis in cm/.05 sec.)

		Standard		T 53-8		Packboard	
		Walk	Run	Walk	Run	Walk	Run
Forward velocity		3.75 (8.38)	6.13 (13.7)	3.74 (8.35)	6.13 (13.7)	3.77 (8.43)	6.26 (14.0)
"Ear"	up	0.7 (2)	1.8 (4)	0.7 (2)	1.8 (4)	0.4 (1)	1.8 (4)
	down	0.7 (2)	1.3 (3)	0.7 (2)	1.8 (4)	0.4 (1)	1.8 (4)
Pack	up	0.7 (2)	2.2 (5)	0.4 (1)	1.8 (4)	0.7 (2)	1.3 (3)
	down	0.7 (2)	2.2 (5)	0.4 (1)	2.7 (6)	0.7 (2)	2.7 (6)
Pouch	up	0.7 (2)	-	0.7 (2)	2.2 (5)	-	-
	down	0.7 (2)	-	0.7 (2)	2.2 (5)	-	-
Shovel handle	up	0.7 (2)	2.2 (5)	1.3 (3)	1.8 (4)	-	-
	down	0.7 (2)	2.7 (6)	0.7 (2)	2.7 (6)	-	-
Thigh 1/3	up	0.7 (2)	2.7 (6)	0.7 (2)	2.2 (5)	0.7 (2)	2.2 (5)
	down	0.4 (1)	2.2 (5)	0.7 (2)	1.8 (4)	0.7 (2)	2.2 (5)
Thigh 2/3	up	1.8 (4)	2.7 (6)	1.3 (3)	3.1 (7)	1.8 (4)	2.2 (5)
	down	1.3 (3)	1.8 (4)	1.3 (3)	2.2 (5)	1.3 (3)	1.8 (4)

With each step there is a rise and fall of the load components as well as the body as a whole. A standard method of expressing this vertical lift is — total feet raised per unit of horizontal distance. The product of this distance of total lift and weight gives a measure of foot pounds which can be considered a measure of part of the work done in forward progression. This method of interpretation has been used in some of the analyses of walking.[12] Energy requirement is related to a power function, i.e., it involves speed as well as foot pounds of work done. The approximation of vertical foot pounds appears, however, to offer a means of comparing the excess vertical movement of different components with different load distributions. The total vertical lift and foot pounds of work per mile for the various components studied by the stroboscopic photography method is presented in Table XIII.

TABLE XIII: VERTICAL LIFT IN FEET PER MILE AND IN VERTICAL FOOT POUNDS PER MILE*

		Standard		T 53-8		Packboard	
		Walk	Run	Walk	Run	Walk	Run
Paces/mile		914	879	914	838	909	821
Forward velocity mph		3.75	6.13	3.74	6.13	3.77	6.26
"Ear"**	ft ft lb	300 42,000	548 76,720	300 42,000	467 65,380	239 33,320	566 79,240
Pack	ft ft lb	390 4290	779 8569	270 1350	550 2750	358 8771	620 15,190
Pouch	ft ft lb	-- --	-- --	510 6120	605 7260	-- --	-- --
Shovel handle	ft ft lb	330 1485	692 3114	360 1620	495 2228	-- --	-- --
Combined components	ft ft lb	720 5775	1471 11,683	1140 9090	1650 12,238	358 8771	620 15,190
Total weight of components analyzed lb.		15.5	15.5	21.5	21.5	24.5	24.5
Mean load rise ft/lb		373	754	423	569	358	620

*Values refer to selected components only

**The vertical motion of the "ear" is used in these calculations as representing the entire body.

It is of interest that the analysis of the T 53-8, which includes components carried anterior to the body as well as posterior, has a greater vertical lift per pound of load, per mile traveled than the two back loads analyzed during walking. During running, however, the average lift per pound, per mile is less with the T 53-8 than the two back loads.

b. Discussion of Stroboscopic Analysis

While few conclusions can be drawn from the data obtained on the single subject used in exploring the stroboscopic technique, it is believed that it has considerable future promise as a valid method for quantifying the dynamic motion factors in pack systems. The present data indicate that the differences to be found among various systems may be small with respect to maximal and minimal values for comparable points. This does not necessarily mean that such differences are unimportant when considered over a sufficient interval of time. It does mean, however, that fairly large groups of subjects will have to be used to establish statistical reliability.

A further point to be made regarding the stroboscopic method is that with the establishment of anatomical landmarks it will be possible to examine the phase relations of the various components -- a matter which cannot be accurately approached with the present data. The importance of these relations was clearly demonstrated in the slow motion picture sequences already described. Quantitative analysis of the relative movement of the pack components with respect to the carrier is most desirable in order to assess the physical energy costs in terms of distribution in time. The total physical energy required to transport two pack systems over a given distance and terrain at a given speed may be the same, but if the movements of the various pack components are not in phase with the movements of the carrier it may be expected that sudden "peaks" in the time distribution of physical energy will occur. These peaks, in the form of bumping and pulling on the man, may produce large changes in the physiological strain of work as well as in comfort to the wearer.

c. Strap Pressure Measurements

The impact and pull of the pack is obviously transmitted to the man as pressure. Karpovich and Hale[8] have developed a pneumatic device for the approximate measurement of pressure under shoulder straps in pack systems. The device employs an aneroid-type blood pressure apparatus for measuring pressures and a pressure pick-up consisting of a piece of heavy rubber tubing. The entire system is calibrated with the application of static pressure across the pick-up through the width of strap to be employed. Dynamic calibrations cannot be made with the apparatus. The records are reported in arbitrary units, read in pounds.

Strap pressure data on the T 53-8, standard combat, packboard and

United Kingdom (Z-2) combination are presented.* Readings obtained on the right and left shoulder have been averaged. The average values in pounds pressure on the measuring device are given for four men before and after, and during walking on a treadmill with a belt speed of 3.5 mph. Table XIV presents the average values measured at the top of the shoulder.

TABLE XIV: MEAN PRESSURE EXERTED BY STRAP ON TOP OF SHOULDERS OF FOUR SUBJECTS (pounds read on meter)

Activity	Packboard	T 53-8	Standard	UK
Standing Before Walking	4.00	1.62	2.11	1.82
During Walking	6.14	3.10	4.56	4.22
Standing After Walking	3.84	1.50	1.97	2.64

The packboard with the distribution of weight carried as one mass on the back with shoulder suspension has a considerably higher average value than the others.

The individual readings for the T 53-8 and standard combat packs are given in Table XV. The values are given in average pressure on right and left shoulders.

TABLE XV: PRESSURE UNDER STRAPS ON TOP OF SHOULDERS OF FOUR SUBJECTS (pounds read on meter)

Subject	Before Walking		During Walking		Standing after Walking	
	T 53-8	Standard	T 53-8	Standard	T 53-8	Standard
We	2.18	3.18	4.27	5.45	2.36	3.00
Pa	2.00	3.18	2.73	4.91	1.73	1.82
Ra	0.91	0.73	1.27	4.09	0.73	0.73
Pe	1.36	1.36	4.09	3.82	1.18	2.36
Mean	1.61	2.11	3.09	4.57	1.50	1.98

A "t" test of the difference between the T 53-8 and the Standard Combat Pack did not indicate statistical significance. Before walking $P < .2$, during walking P approaches .1, and after walking $P < .2$.

*These data are presented through the courtesy of Dr. P.V. Karpovich and Mrs. L.M. Ewing of the Department of Physiology, Springfield College, Contract No. DA44-109-qm-912.

The data obtained with the pneumatic strap pressure gauge suggest that in the T 53-8 system some of the weight bearing force has been transferred to the pelvis where it can be transmitted to the ground through bone as recommended by Lippold and Naylor.[9, 10]

5. General Summary and Conclusions

A beginning has been made in the development of test criteria for physiologic and performance tests of load-carrying systems. A discussion of experimental rationale for field and laboratory studies has been presented.

The T 53-8 was generally superior to other systems tested when compared in situations (such as running and "hitting the dirt") where dynamic considerations are paramount.

Measures tried included metabolic rate studies, performance tests, motion analyses based on stroboscopic photography, and shoulder strap pressure data.

The studies of metabolic rate on the treadmill suggested that there was an advantage to the T 53-8 system at higher speeds such as 5.0 mph. At 2.5 and 3.5 mph the T 53-8 was no different or slightly inferior to the Standard Combat Pack on the metabolic rate criterion. In general, the increment of energy expenditure with change in velocity is a promising method for studying differences, the T 53-8 appearing superior to the Standard Combat Pack in a two-speed test at 3.5 and 5.0 mph.

Performance tests studied included "hitting the dirt," and running over an obstacle course of tires placed in a zigzag manner to accentuate vertical, lateral, anteroposterior and angular acceleration. The latter test readily discriminated between combat pack loads and a packboard load; however, the differences in time trials between the T 53-8 and the Standard Combat Pack were not significant. The differences were so small that discrimination of this small difference in design would not be likely even with many additional trials.

Slow motion movies of men carrying loads over this obstacle course were very effective in revealing the problems of accelerating and decelerating of loads. These problems can be logically divided into two categories. One type of problem occurs when loads are closely coupled to parts of the body that are rapidly accelerating and decelerating with each step. This is clearly illustrated by the increased energy required with loads that are coupled to the motions of the thigh. In the other problem the load moves out of phase with the body, resulting in "bumps" and "pulls" on the carrier, both of which increase the physiologic and psychologic strains on the wearer.

Three subjects were able to progress forward more rapidly while "hitting the dirt" at eight-yard intervals with the T 53-8 than with the Standard Combat Pack.

Motion analyses of one subject by the stroboscopic technique, using "scotchlite" reflectors were presented. In the absence of comparative data on a number of subjects, the interpretations are limited, but the power of this technique is apparent.

6. Recommendations

a. That slow motion pictures be obtained of laboratory and field tests of load-carrying systems because of the important qualitative interpretations which can be made, and because of the usefulness of the technique in insuring comparability of different tests.

b. That the zigzag running course of tires be used as a standard course for slow motion movies of load-carrying.

c. That the following procedures which offer promise as test methods be studied further for validation as evaluation criteria.

(1) A two-speed treadmill test, using the increase of energy with increasing speed as the measurement.

(2) Dashes of 25, 50 and 100 yards.

(3) "Hitting the dirt."

(4) Stroboscopic photography analysis of the excess motion of load components.

d. That the Quartermaster Research & Development Field Evaluation Agency and other agencies having facilities for the determination of subjective reactions in large numbers of subjects undertake studies of the preferences of men for high and low pack loads, with and without fore-aft balance.

7. Acknowledgements

We are grateful to Dr. R.W. Newman, Chief, Physical Anthropology Section of the Stress Physiology Branch for his skin-fold determinations of the test subjects' body fat. Appreciation is expressed to Messrs. F.R. Winsmann and N.J. Morana of the Stress Physiology Branch for their assistance in the collection of the test data. The stroboscopic photography was accomplished by Mr. L.J. Moore of the Graphic Arts Branch, Research Services Office; and Mr. H.R. Perry, Cartographer of the Environmental Research Branch made the figures for the report.

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